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CATASTROPHIC CORAL MORTALITY IN THE REMOTE CENTRAL PACIFIC OCEAN: KIRABATI PHOENIX ISLANDS

BY

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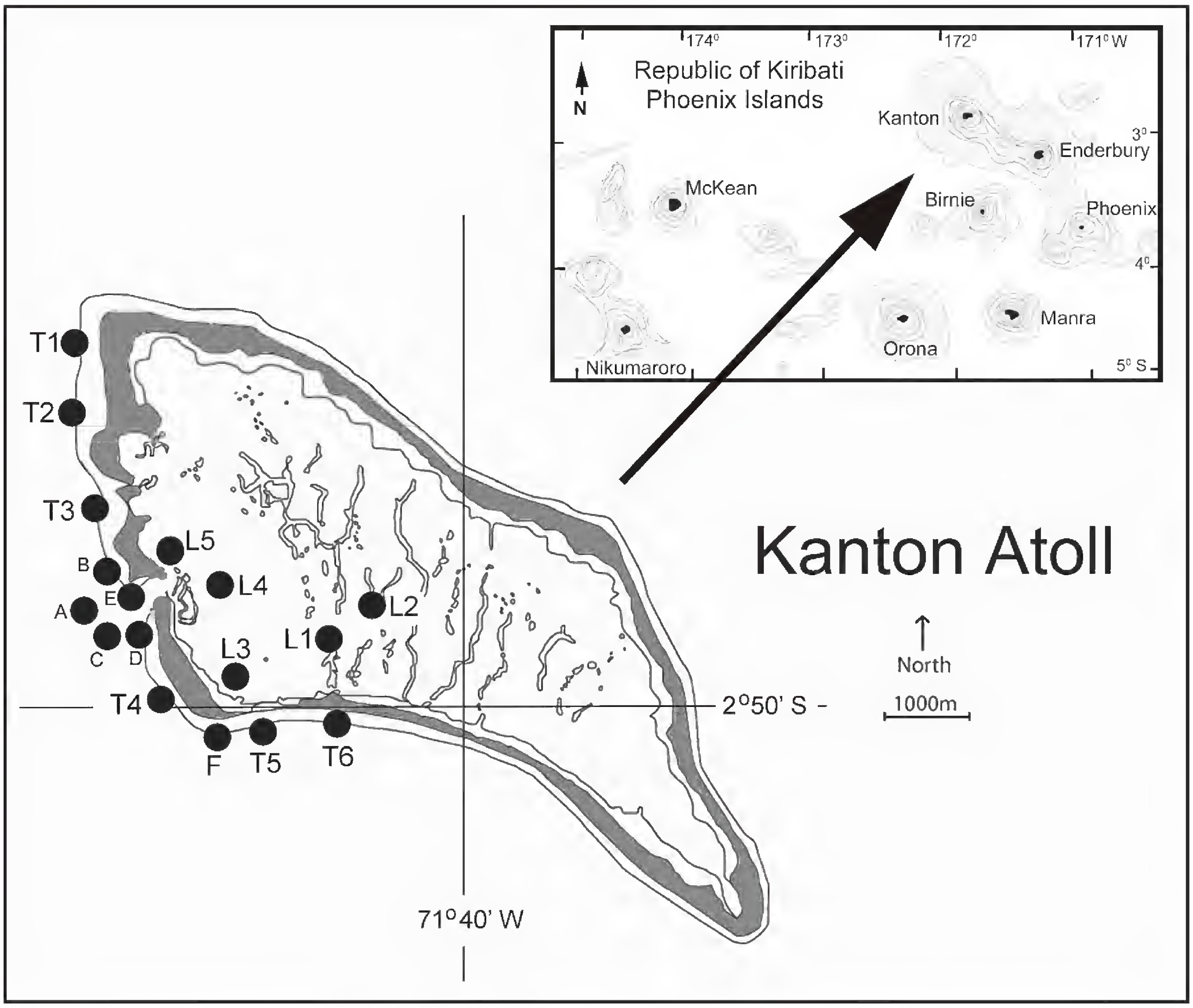

Figure 1. Location map for K anton Atoll survey stations in the Phoenix Islands, Republic of Kiribati in the Central Pacific Ocean visited by the crew of the RV Heraclitus, November 22 through December 19, 2004. Stations include (1) Offshore Transects: T1 – T6, (2) Offshore Observational Dives: A – F, and (3) Lagoon Snorkel/Health and Vitality Dives: L1 – L5

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ABSTRACT

Quantitative and qualitative surveys in November-to-December 2004 revealed near 100% coral mortality in the lagoon of Kanton Atoll and 62% mortality on the outer leeward reef slopes of this island as well as elsewhere throughout the Kiribati Phoenix Islands in the Central Equatorial Pacific Ocean. Most dead colonies were in growth position. Colonies were encrusted with coralline algae indicating they had been dead for 1 to 2 years, thus dying just after an expedition by the New England Aquarium in July 2002 which declared the region one of the most pristine reefs left in the Central Pacific.

Fish populations did not seem reduced to the same levels as the stony corals but only 153 species of fish were identified at the study sites. Apex predators and key indicator fish species were present suggesting little impact from overfishing. Populations of invertebrates, now dominated by sponges, were also seemingly reduced inside the Kanton Atoll lagoon. Thirty-six species of living corals were identified along 480 m^2 of transects. Five of eight coral genera represented <1% of the bottom cover. Many of the living corals found were less than 10 cm in diameter suggesting recruitment has occurred since the mass mortality.

Bleaching Hot Spot Analysis by National Oceanographic and Atmospheric Administration / National Environmental Satellite, Data, and Information Service (NOAA/NESDIS) satellite monitoring revealed a record high of 16 degree heating weeks (DHW) around the Phoenix Islands between August 2002 and March 2003. The Kanton Atoll lagoon has a residence time approaching 50 days, there is no significant source of land-based pollution and there was no sign of any destructive fishing practices. Hence, the exposure to excessively high water temperatures for over six months killed the coral-reef community of Kanton Atoll lagoon and caused the excessive loss of coral species and cover throughout the Phoenix Island group. These observations provide further evidence that coral reefs in the most remote part of the Central Pacific Ocean are not isolated from the effects of global warming.

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INTRODUCTION

Coral reefs are now endangered on a planetary scale due to pollution, diseases, overfishing, dynamite and cyanide fishing, and bleaching most likely caused by rising ocean temperatures. Anthropogenic stresses to coral reefs, applied at nested temporal and spatial scales, are significant contributors to the decline of coral-reef ecosystems noted in the Caribbean, Western Atlantic and Southeast Asian reefs (Dustan, 2003; Nystrom et al., 2000, Knowlton, 2001). Coastal reefs located near densely inhabited and developed land masses, as in the Florida Keys (Dustan, 2003) and the Indonesian Archipelago (Bryant et al., 1998; Burke et al., 2002) appear to be at greatest risk. Regardless of location, reef ecosystems are now becoming more affected by increases in sea-water temperature, ultraviolet radiation and perhaps by CO_2-induced changes in the carbonate state of sea water (Kleypas et al., 1999). Widespread mass bleaching of corals has been reported repeatedly in the Pacific Ocean, Indian Ocean and the Caribbean Sea since 1982. In 1998, extensive coral bleaching occurred in all the tropical seas including the Indian Ocean and Central Pacific (Goreau et al., 2000).

Throughout this time, the Phoenix Islands, with the nearest neighboring islands over 600 km away, survived unscathed in their remote equatorial Central Pacific location. In 2000 and 2002, the New England Aquarium expeditions found the reef corals vibrant and fish communities robust with a full suite of apex predators (Stone et al., 2002). They declared the islands as one of the last reef wilderness areas--a small remaining portion of the primal ocean. “Our most valuable discovery was that the Phoenix Islands as an entire coral ecosystem (has) survived largely intact making them one of the last havens of ocean wilderness” (Stone et al., 2004).

Kanton Atoll

Kanton Atoll, discovered by westerners in the early 19th century, became one of the richest sperm-whaling grounds in the South Pacific and, like many coral reefs, was named after the American whaling ship, Canton that was wrecked there in 1854. The name was changed to Kanton by the Kiribati government, along the renaming of Gardner to Nikumaroro, Sydney to Manra, and Hull to Orono. The land on the atoll covers 3½ square miles. The coastline is bordered by a fringing reef that extends from 2 to over 40 meters deep. Guano was mined from Kanton and some of the other Phoenix Islands for a period of time until it was no longer profitable. During World War II, Kanton was a United States Air Force base. After the war until 1958, the airfield was used as a refueling station for transpacific flights; the runway still remains on the north side of the island, close to the village. There is also a seaplane landing strip still clearly marked in the lagoon. From 1960-68 the island was used as a satellite tracking station by the National Aeronautics and Space Administration. While there are no permanent inhabitants in the Phoenix Islands, a small community of less than 40 people, including 14 adults and associated children from other islands of Kiribati, live on the island.

Kanton is an atoll with just one entrance to the lagoon (Fig. 1). Tidal currents in the pass can exceed more than 10 knots. The lagoon is less than 10 meters deep around the entrance and is just behind the small island that lies inside the entrance. The majority

of the lagoon consists of sandy bottom with scattered patch reefs and isolated corals. The island and lagoon channel passes were modified by the U.S. Government during the WW2 Pacific campaign. The southern pass was dredged and the entrance to the lagoon extensively modified to allow large ships to maneuver within the lagoon. A seaplane landing strip area was deepened and extended out to the middle of the lagoon where there are long lines of shallow coral patches. There is a sharp gradient of decreasing coral cover towards the interior of the lagoon. The dredging operation modified the hydrodynamics of the lagoon, perhaps decreasing the water residence time and also lowering the water level within the lagoon owing to increased drainage efficiency through the deepened tidal passes (Jokiel and Maragos, 1978).

MATERIALS AND METHODS

The 84-foot research vessel R/V Heraclitus has been chartered by the Planetary Coral Reef Foundation (PCRF) since 1995 to study coral reefs in the Red Sea, Indian Ocean, South China Sea and the North and South Pacific Ocean (www.pcrf.org/science.index.html). During an expedition to the Phoenix Island group in November and December 2004, the crew of this ship voyaged to Manra, Enderbury, Kanton, McKean and Nikumroro Islands (Fig. 1). Three observational dives were conducted at Manra Island on November 22, 2004 and three dives at Enderbury Island on November 25, 2004 (Table 1). From November 26-to-December 8, 2004, the ship was stationed at Kanton Island where the crew conducted 27 dives (6 transect dives and 21 exploratory dives) along the fringing reef, as well as five snorkel dives inside the lagoon (Fig. 1, Table 2).

Table 1. Dive location at Manra, Enderbury, McKean and Nikumroro Islands.

Dive	Date	Island	Site Name	Latitude	Longitude
1	22 Nov	Manra	Western Point	S 02°50.1’	W 171° 41.1’
2	22 Nov	Manra	Southern Tip	S 04° 28.2’	W 171° 15.5’
3	22 Nov	Manra	Northern Tip	S 04° 26.1’	W 171° 15.6’
4	25 Nov	Enderbury	NW of Old Camp	S 03° 06.7’	W 171° 05.8’
5	25 Nov	Enderbury	NW of Old Camp	S 03° 06.7’	W 171° 05.8’
6	25 Nov	Enderbury	SW of radio tower	S 03° 09.2’	W 171° 05.6’
7	14 Dec	McKean	Western Point	S 04° 27.2’	W 171° 16.0’
8	14 Dec	McKean	Southern Tip	S 04° 28.2’	W 171° 15.5’
9	14 Dec	McKean	Southern Tip	S 04° 28.2’	W 171° 15.5’
10	16 Dec	Nikumroro	Southern Tip	S 04° 42.1’	W 174° 29.7’
11	16 Dec	Nikumroro	Southern Tip	S 04° 42.1’	W 174° 29.7’
12	16 Dec	Nikumroro	Mid-South section	S 04° 41.3’	W 174° 31.5’
13	16 Dec	Nikumroro	Lagoon Passage	S 04° 40.0’	W 174° 32.8’
14	17 Dec	Nikumroro	Wreck	S 04° 39.8’	W 174° 32.8’
15	17 Dec	Nikumroro	North of Wreck	S 04° 39.4’	W 174° 32.7’
16	17 Dec	Nikumroro	Passage Point	S 04° 40.3’	W 174° 32.7’
17	19 Dec	Nikumroro	Passage Point	S 04° 40.3’	W 174° 32.7’
18	19 Dec	Nikumroro	Passage Point	S 04° 40.3’	W 174° 32.7’

After Kanton Island, the crew made three observational dives at McKean Island on December 14, 2004 and nine dives along the leeward reefs of Nikumroro Island (also known as Nikumaroro) from December 16-to-19, 2004 (Table 1).

Table 2. Dive/snorkel surveys at Kanton Atoll (see Fig. 1 for station location)

Dive #	Date	ID	Site Name	Latitude	Longitude
1	26 Nov	A	Kanton Pass	S 02° 48.8'	W 171° 43.9'
2	26 Nov	B	RVH anchorage	S 02° 48.7'	W 171° 43.1'
3	29 Nov	T2	Transect 2	S 02° 46.640'	W 171° 43.492'
4	29 Nov	T3	Transect 3	S 02° 47.768'	W 171° 43.313'
5	29 Nov	T4	Transect 4	S 02° 49.623'	W 171° 42.713'
6	29 Nov	C	President Taylor	S 02° 48.9'	W 171° 43.0'
	29 Nov	D	Boat Passage	S 02° 48.9'	W 171° 42.9'
7	30 Nov	T1	Transect 1	S 02° 46.129'	W 171° 43.431'
8	30 Nov	B	RVH anchorage	S 02° 48.7'	W 171° 43.1'
9	1 Dec	E	Outer Boat Passage	S 02° 48.8'	W 171° 43.1'
10	1 Dec	E	Outer Boat Passage	S 02° 48.8'	W 171° 43.1'
11	2 Dec	T6	Transect 6	S 02° 50.076'	W 171° 41.107'
12	2 Dec	B	RVH anchorage	S 02° 48.7'	W 171° 43.1'
13	2 Dec	T5	Transect 5	S 02° 50.168'	W 171° 42.077'
14*	3 Dec	L1	Lagoon 1	S 02° 49.260'	W 171° 40.986'
15*	3 Dec	L2	Lagoon 2	S 02° 48.712'	W 171° 42.304'
16*	3 Dec	L3	Lagoon 3	S 02° 48.712'	W 171° 42.304'
17*	3 Dec	L4	Lagoon 4	S 02° 48.789'	W 171° 42.675'
18*	3 Dec	L5	Lagoon 5	S 02° 48.624'	W 171° 42.906'
19	3 Dec	C	President Taylor	S 02° 48.9'	W 171° 43.0'
20	3 Dec	B	RVH anchorage	S 02° 48.7'	W 171° 43.1'
21	5 Dec	B	RVH anchorage	S 02° 48.7'	W 171° 43.1'
22	5 Dec	B	RVH anchorage	S 02° 48.7'	W 171° 43.1'
23	5 Dec	F	SW point	S 02° 50.2'	W 171° 42.1'
24	6 Dec	C	President Taylor	S 02° 48.9'	W 171° 43.0'
25	6 Dec	D	Boat Passage	S 02° 48.9'	W 171° 42.9'
26	6 Dec	F	SW point	S 02° 50.2'	W 171° 42.1'
27	7 Dec	B	RVH anchorage	S 02° 48.7'	W 171° 43.1'
28	7 Dec	B	RVH anchorage	S 02° 48.7'	W 171° 43.1'
29	7 Dec	E	Outer Boat Passage	S 02° 48.8'	W 171° 43.1'
30	7 Dec	F	SW point	S 02° 50.2'	W 171° 42.1'
31	8 Dec	B	RVH anchorage	S 02° 48.7'	W 171° 43.1'
32	8 Dec	B	RVH anchorage	S 02° 48.7'	W 171° 43.1'

Surveys

The health and vitality of the Kanton Reef lagoon was studied using Vitareef, a rapid assessment technique that statistically documents the phenotypic condition of reef coral populations (Dustan, 1993). Vitareef condition codes provide a spectrum of coral condition categories ranging from an unblemished colony (presumed healthy) to diseased, bleached, physically damaged, or recently dead. Coral populations were surveyed during five snorkel excursions in the lagoon at maximum depths of 7-to-9 meters (stations L1 - L5, Table 2 and Fig. 1). Images of corals were recorded using digital video transects (SONY DCR-TRV30). The New England Aquarium expedition in2000 had noted that the large tabular and staghorn colonies of the genus *Acropora* represented >80% coral coverage in the lagoon (Stone et al., 2001). Vitareef analysis was used to categorize the condition of these colonies since it was the dominant genus and easily recognizable in video imagery.

Six digital 20m-long-image transects, approximately one nautical mile apart, were conducted along the outer leeward reef of Kanton using a digital underwater camera (Sony Cybershot DSC-P8 with red filter). Three transects were run northwest of the pass into the lagoon and three were completed to the south and east of the pass. These dives resulted in about 30 man hours of observation (Table 2, Figure 2: T1 – T6). Transect locations covered as much of the leeward reef extent as possible and sites were chosen to be representative of the entire reef ecosystem. A minimum of four divers descended at each survey site to census corals, fish, and indicator invertebrate populations. Each 20-meter transect was established at a depth of between 5-and-10 meters along a depth contour and a surface buoy was tethered to each end. A bearing was taken from buoy A to buoy B and the boat tender took GPS coordinates at both surface-buoys (Table 2). An evenly spaced series of approximately 30 consecutive still images, each 40-to-50 cm above the substrate, were taken along the 20-meter transect to estimate percent cover.

Coral cover (percent projected cover to the surface) was estimated from transect images using PointCount99 (Porter et al., 2001). The program generated 15 random points on each image which were identified into one of the following categories: live coral to genus, dead coral, other (including sand, rubble, rock, etc.) and unidentified when it was not clear what the point represented. A total of 186 frames (2,790 points), covering an estimated 46m^2 along the six transects, were used to estimate percent coverage.

At each site, coral-species inventories were conducted by divers because transect photos could not represent fully all coral species observed within an area. Coral genera, and species level were identified when possible on 2 meters either side of the transect line (an 80 m^2 belt transect) totaling 480 m^2 for all six transects. Divers searched under ledges and in between rubble for small patches of live coral, as coral cover was extremely low. Identifications were checked using Veron (2000) for reference and are reported in this communication at the taxonomic level of genus.

Fish surveys, including species identification and population counts, were conducted by divers in the area surrounding each transect to a maximum depth of 15 meters. Fish were identified visually using Lieske and Myers (1997) and Randall et al. (1997) for reference. Both coral and fish surveys were conducted during a 45-minute period during each transect dive.

The general status of the reef community was ascertained using towed diver surveys. A GPS track was taken along the leeward side of the island at the 2-5 meter contour of the reef and observations of both the land and the reef were recorded. Terrestrial observations included any prominent man-made or environmental landmarks. Submarine observations included estimates of live and dead coral cover, distinguishing landmarks such as large coral bommies, coral or sand patches, bottom structure and depth contours.

General information, secchi disk readings for visibility, cloud cover and sea state were also recorded at each site. Additional video recordings were also taken during the dives at the other islands of the Phoenix group.

RESULTS

Kanton Atoll Lagoon – Reef Corals

Every colony of *Acropora* recorded by video footage taken inside the lagoon (n=1,979) was dead, but the colonies could still be identified as to genus. These dead colonies were overgrown by algal mat communities which in turn were coated with fine sediments giving the once rich coral community a ghost-like graveyard appearance (Fig. 2). One video transect showed a small patch of live *Pavona* and a living *Millepora* colony at site L1.

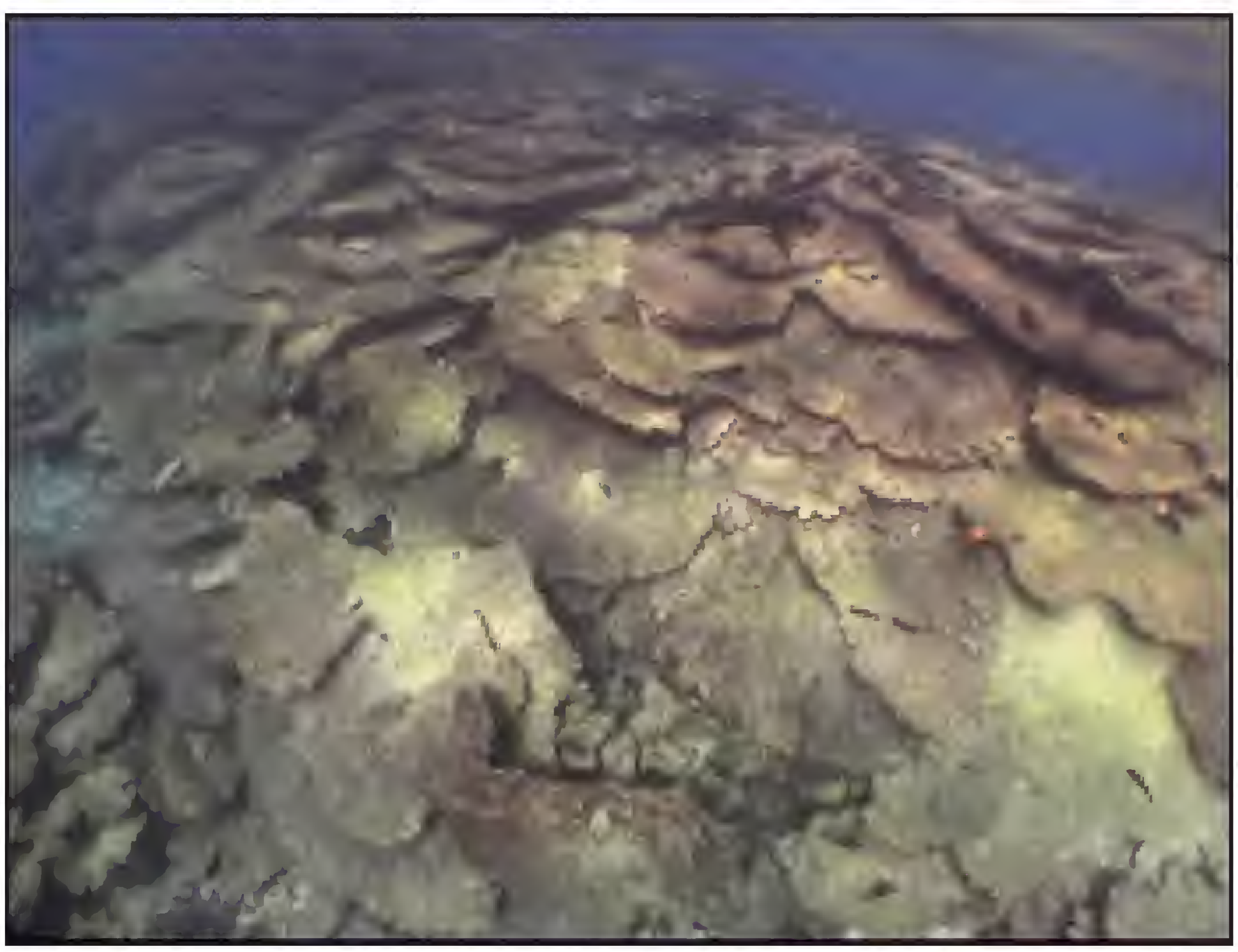

Figure 2. Dead *Acropora* colonies inside the lagoon at Kanton Island.

Kanton Atoll Leeward Reef – Reef Corals

Quantitative and towed surveys revealed the entire leeward reef system had suffered widespread mortality. Coral cover along the six transects on the leeward side of Kanton Island was estimated to contain 16.2 % live coral cover and 62.1% dead coral cover (Table 3, n = 186 digital images). *Echinsopora* (6.56% cover) and *Montipora, Favia* and *Goniastrea* were the most abundant corals. Five of the eight genera recorded from the PointCount99 analysis represented less than 1% of the live coral-bottom cover. These included *Porites, Goniastrea, Platygyra, Hydnophora and Millepora* There was little difference between the 6 areas with the exception of transect 5 (Table 4). This location displayed the highest percentage of live coral cover at 38.24% and dead coral cover of 53.92%. This site, unlike the other transects, was dominated by large and well-developed colonies of *Echinopora* (29.22% cover). The majority of coral colonies were small (< 10 cm diameter) and possibly recent recruits.

Within the 480 m^2 of transects, divers recorded 23 genera of stony corals (Table 5). There were 84 colonies of *Pocillopora* of which 8 were alive and 76 were dead. On the Kanton Island Fringing reef, large amounts of macroalgae were observed to be smothering live coral colonies and encrusting coralline algae were actively growing over live coral colonies, especially *Pocillopora* (Fig. 3).

Table 3: Summary of living and dead coral cover on the leeward side of Kanton Island. Results were taken from 186 images recorded during six transects. The total live coral figure is derived from the percentage cover of the 8 identifiable coral genus plus unidentifiable corals.

Substrate	**Cover (%)**
Echinopora	6.56
Montipora	3.15
Favia	2.72
Porites	0.57
Goniastrea	0.47
Platygyra	0.57
Hydnophora	0.72
Millepora	0.04
Unidentified Live Coral	1.40
Total Live Coral (sum a-i)	16.20
Total Dead Coral	62.11
Total Other	15.92
Total Unidentifiable	5.77

Kanton Atoll – Invertebrates

The only invertebrates observed inside the Kanton lagoon were sponges at the L3 site and lobsters at L4 site. Thirteen genera of invertebrates were observed along the leeward reef of Kanton Island (Table 5). Hydroids, on dead as well as live coral, were the most prevalent invertebrates. Zooanthids were found predominantly on rock and rubble throughout the survey area; one *Acanthaster planci* and two *Culcita novaeguineae* were observed.

Table 4. Percent cover of live and dead reef coral on the on the leeward side of Kanton Island (Transects T1-T6). The total live coral figure is derived from the percentage cover of the eight identifiable coral genera plus unidentifiable corals.

Stony Coral Genera	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
Echinopora	0.8	4.2	1.2	0.5	29.2	0.0
Montipora			12.5		0.6	2.9
Favia	0.3	5.1	3.5	1.4	4.1	
Porites	2.1	0.2	0.5		0.2	0.9
Goniastrea	1.9		0.7		0.2	0.3
Platygyra		0.4	0.0		1.4	2.0
Hydnophora		2.1			1.4	0.6
Millepora		0.2				
Unidentified live coral	1.1	1.9	1.3	1.6	1.2	1.2
Total Live Coral Cover	6.1	14.1	19.7	3.5	38.2	7.8
Total Dead Coral Cover	72.8	64.8	59.2	77.0	53.9	44.9
Total Other	17.9	15.2	19.5	9.7	0.6	39.1
Unidentifiable	3.2	5.9	1.7	9.9	7.3	8.1

Table 5: Invertebrates observed during transect dives on the Kanton fringing reef.

Common name	**Genus**
Giant clams	*Tridacna*
Long armed sea star	*Linckia*
Pin cushion sea star	*Culcita*
Hydroids	*Halocordyle*
Black spined sea urchin	*Diadema*
Pink spined sea urchin	*Echinometra*
Christmas tree polychaete	*Spirobranchus*
Zooanthids	*Palythoa*
Leather coral	*Sarcophyton*
Crown of thorns sea star	*Acanthaster*

Kanton Atoll - Fish Surveys

At Kanton Island, divers observed 153 species of fish during the six transect dives and five snorkel surveys (Tables 6 and 7). Inside the lagoon, the fish community varied with substrate. At site L1, a sandy bottom only a meter deep with scattered bommies of live coral, the predominant fish was *Chromis viridis* (blue green chromis). *Rhinecanthus aculeatus* (Picasso trigger fish) was observed at L1 and L2, as would be expected for a sand/rock lagoon substrate. Closer to the channel and leading to the outside of the lagoon, the size of fish and their density increased.

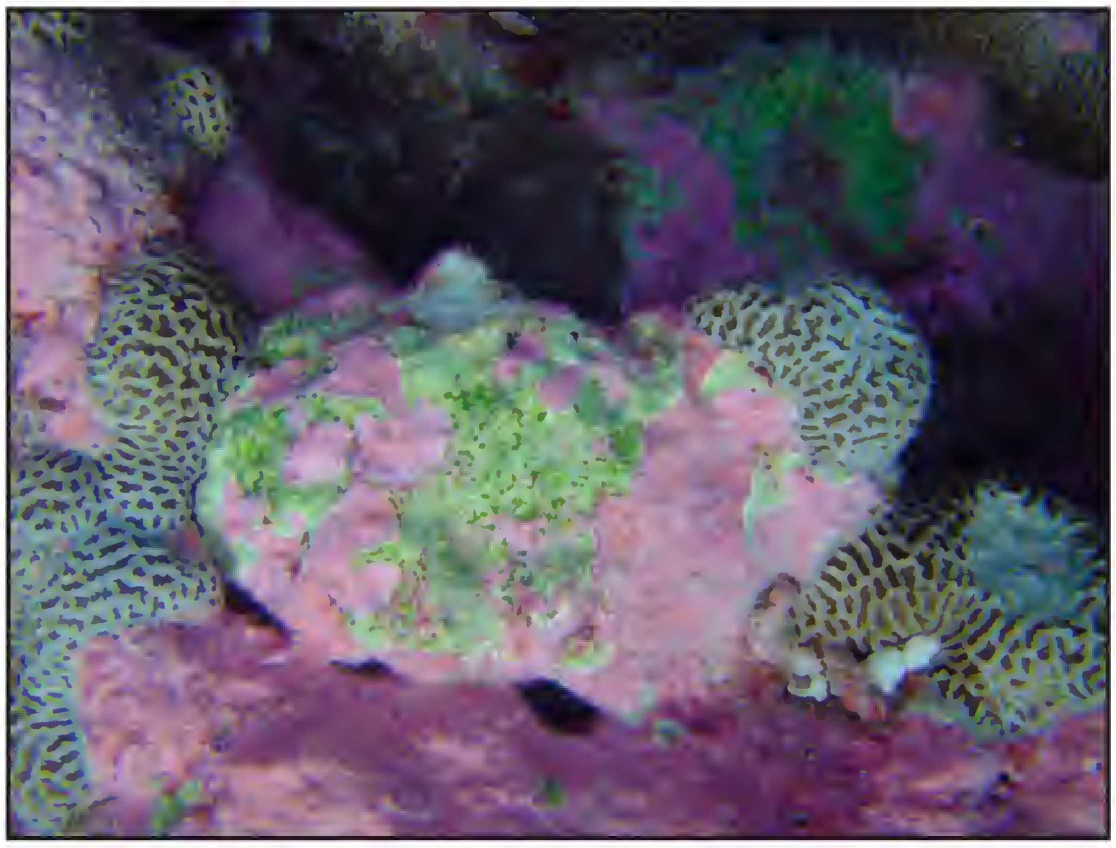

Figure 3. Red coralline algae encrusting a colony of *Platygyra* at Kanton Island.

All the offshore leeward sites (T1-T6) had relatively large and diverse fish communities. At site T-6, we saw large schools (<1000 individuals) of predatory *Caranx melampygus* (bluefin trevally) and 200 *Lutjanus bohar* (red snappers), the highest number of these observed at any of the sites. Dense populations of *Cheilinus undulatus* (napoleon wrasse) were recorded at all six transect sites, peaking at 40 for site T6. At site T5, a fully grown napoleon wrasse which had lost its entire tail was still able to maneuver about the reef. Divers reported relatively few dogtooth tuna, bigeye trevally and flowery cod.

Phoenix Island Group – General Observations

The four other Phoenix Islands visited by the R/V Heraclitus -- Manra, Enderbury, McKean and Nikumroro-- all had reef ecosystems in a similar state to that of Kanton Island with fish life relatively abundant and stony corals predominately dead. Apex predators were common and fish were abundant on Manra and Enderbury Islands. Black tip sharks (*Carcharhinus melanopterus*), white tip sharks (*Triaenodon obesus*) and grey reef sharks (*C. amblyrhychos*) were prevalent and there were luxuriant populations of red snapper, *Lutjanus bohar.*

The reef habitat of Manra Island was composed of a sandy bottom interspersed with coral patches. Thirteen genera of corals were observed during approximately 10 man hours of observations (Table 8). Patches of dead stony corals covered areas ranging in size from 2-to-20 meters in diameter. The majority of their substrate was covered with macroalgae with some filamentous and coralline algae. In some areas, algal cover was estimated to be as high as 95%. *Pocillopora* was especially affected by the coralline algae; only two live colonies were observed throughout all three dives. Invertebrates observed at Manra Island included a variety of sponges, a few crown of thorn sea stars and numerous hydroids covering the corals.

Table 6. Fish species identified during the six 45-minute transect dives (T1, T2, T3, T4, T5, T6) at a depth of less than 15 meters and during the 10-minute snorkel surveys (L1, L2, L3, L4) at a depth of less than 5 meters. A plus sign "+" indicates that individuals exceeded recorded counts.

Species	**Common Name**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**L1**	**L2**	**L3**	**L4**
TUNA and PELAGICS											
Gymnosarda unicolor	Dogtooth Tuna	2	0	0	0	0	0	0	0	0	0
Euthynnus affinis	Mackerel Tuna	0	0	0	0	0	0	0	0	0	0
Scomberoides lysan	Double-spotted Queenfish	30	7	0	0	0	0	0	0	0	0
Elegatus bipunnulata	Rainbow Runner	0	0	0	0	25	20	0	0	0	0
JACKS											
Caranx sexfasciatus	Bigeye Trevally	0	0	0	0	0	2	0	0	0	0
Caranx melampygus	Bluefin Trevally	100+	20	30	40	200+	10^3+	0	0	0	8
Caranx lugubris	Black Trevally	20	0	0	1	3	150+	0	0	0	3
REEF PREDATORS											
Sphyraena qenie	Chevron Barracuda	0	0	0	0	0	0	0	0	0	0
Cheilinus undulates	Napoleon Wrasse	30	10	10	10	30	40	0	0	0	0
Epinephelus fuscoguttatus	Flowery Cod	0	0	2	0	0	0	0	0	0	0
Plectropomus laevis	Footballer Trout	1	0	0	0	0	0	0	0	0	0
Aprion virescens	Green Jobfish	0	0	0	0	0	0	0	0	0	0
Lutjanus bohar	Red Bass	40	50+	20	20	100	200	0	0	5	12
Macolor macularis	Midnight Seaperch	0	0	0	0	0	0	0	0	0	0
SHARKS and RAYS											
Carcharhinus melanopterus	Blacktip Reef Shark	0	2	0	1	0	0	0	0	0	0
Carcharhinus amblyrhynchos	Grey Reef Shark	3	1	0	0	2	1	0	0	0	0
Triaenodon obesus	Whitetip Reef Shark	0	1	2	2	0	0	0	0	0	0
Manta birostris/alfredi	Manta Ray	0	0	0	1	0	0	0	0	0	0

Table 7. Population counts grouped by fish families recorded at transect/snorkel sites. The number of species identified within each family below counts. A plus sign "+" indicates that individuals exceeded recorded counts.

Family		T1	T2	T3	T4	T5	T6	L1	L2	L3	L4
Serranidae	counts	40	27	15	16	46	26	5	2	2	4
	species	8	6	4	5	6	4	1	1	1	2
Lutjanidae	counts	65	358+	99+	43	204	256			25	43
	species	3	4	4	3		3			2	3
Saridae	counts	63+	60+	37	27	10	125+			70	35
	species	5	2	3	3	1	5			4	3
Saridae	counts	234+	240+	75	94	90	96	15		34	55
	species	11	8	6	5	8	7	1		2	4
Balistidae	counts	46	35	9	10	50	63	6	4	2	4
	species	6	5	4	4	5	5	1	1	1	2

On Enderbury Island, stony coral conditions were similar. Seventeen genera of coral were counted during three dives of approximately 10 man hours (Table 8). The island was predominately sand which was observed washing out onto the reef. Encrusting coralline algae were prevalent, especially on *Pocillopora* and *Platygyra.* Only two coral colonies were observed with some bleaching and no crown of thorns was seen. Many colonies of *Porites* were heavily covered with *Spirobranchus giganteus* (Christmas tree polychaete worms) with as many as up to 50 on a single colony. Other invertebrates at Enderbury Island included large tridacnid clams, cowries, sea stars and anemones.

At McKean Island, dead coral colonies were overgrown with large amounts of filamentous, macro and red coralline algae. Thirteen genera of corals were noted during approximately 12 man hours including *Plerogyra* which was also seen at Nikumroro, and *Turbinaria* , which was not seen at any other reef (Table 8). Estimated live hard coral cover was no more than 5% in all zones from 7-to-30 meters. Fish populations were abundant and diverse and an estimated 30 green moray eels, Gymnothorax funebris, were observed. Reef-dwelling invertebrates included tridacnid clams, sea cucumbers, sea stars and one large black spined sea urchin.

At Nikumroro Island, 21 genera of stony corals were identified during approximately 34 man hours of observations (Table 8). The western side of Nikumroro had the highest live coral cover of any dive site throughout the five Phoenix Islands visited. In some areas, live coral cover was estimated to be as high as 50%. On the northern point, however, the reef was similar to the rest of the reefs of the Phoenix Islands with low live coral cover, high algal coverage and high fish diversity.

Table 8. Stony coral genera recorded at Manra, Enderbury, Kanton, McKean and Nikumroro Reefs. ("X" indicates an observed stony coral genus).

Stony Coral	Manra	Enderbury	Kanton	McKean	Nikumroro
Acropora	X[1]		X	X	X
Pocillopora	X[2]	X[3]	X	X	X
Porites	X	X[4]	X	X	X
Montipora	X	X[5]	X	X	X
Hydnophora	X	X	X		
Favites	X	X	X	X	X
Fungia	X	X	X	X	X
Halomitria	X	X	X	X	X
Leptoria	X	X	X		
Goniastrea	X	X	X		X
Favia	X	X	X	X	X
Lobophyllia	X	X	X	X	X
Platygyra		X[3]	X		X
Coscinarea		X	X		X
Cyphastrea		X	X		
Leptoseris		X	X		X
Echinophillia		X			
Echinopora			X		X
Pavona varians	X	X	X	X	X
Psammacora			X	X	X
Montastrea			X		X
Oxypora			X		X
Herpolitha			X		X
Acanthastrea			X		
Plerogyra				X	X
Turbinaria				X	
Total # of genera	13	17	23	13	20

[1]Very little *Acropora* observed. [2]Corraline Algal overgrtowth - 99% dead. Only two healthy colonies observed. [3]Both badly affected by coralline algae. [4]Heavily infested with Christmas tree worms. [5]Dominant genus above 5 meters.

DISCUSSION

The Phoenix Islands are remote from land and the usual stressors associated with land-based sources of pollution. They are not normally subject to cyclonic storm activity owing to their equatorial geography and there is little influence from the small local human population. Earlier surveys at Kanton Island suggested that dredging operations during WWII had influenced the distribution of reef corals by changing the circulation patterns within the lagoon (Jokeil and Maragos, 1978; Smith and Jokeil, 1978). Three of four island passes were closed and an additional 8-meter-deep channel was cut through the atoll rim for access by ships. A turning basin was dredged at the end of this ship

channel and an additional area dredged to allow seaplanes to land. Closing the tidal passes did not reduce the tidal volume exchange, but it significantly altered the circulation velocities and direction of flow within the lagoon creating an area of high turbidity and degraded reef. However, aside from the physical alterations at Kanton Atoll, the authors reported no obvious deleterious human impacts on any of the five islands (Henderson, et al., 1978).

The coral community at the entrance of Kanton Atoll lagoon was described in 2000 and 2002 as the most highly developed *Acropora* community seen anywhere in the world (Stone et al., 2001) and exceptional in its physical development (Stone et al., 2002). These observations meshed well with earlier surveys in 1972-73 that described a well-developed *Acropora* community near the tidal passes as being very rich with a decreasing gradient of abundance farther into the lagoon (Jokeil and Magagos, 1978). Sadly, in December 2004, all the *Acropora* colonies inside the lagoon were found dead. The dead colonies were mostly intact, with a few turned over or with shattered tiers. The only living coral seen was a monospecific patch of *Pavona.* In 2002, Stone et al. reported minor bleaching in the lagoon on colonies of *Goniastrea*, *Echinopora* and small numbers of *Acropora* (Stone et al, 2002). They also reported low numbers of partially bleached colonies of *Pocillopora* which they attributed to being normal for a healthy coral community. There was no indication at the completion of their study in July 2002 that the community was significantly stressed.

There is also no indication of widespread coral mortality due to predatory invertebrates. In both the 2000 and 2004 studies, observations of invertebrate coral predators were rare (Stone et al., 2001). One *Acanthaster planci* was observed during both survey periods and only two *Culcita novaguineae* were observed during all the 2004 PCRF dives.

The only possible scenario for the dramatic loss of coral reefs of the Kanton area between the time of the last survey conducted by the New England Aquarium in July 2002 and the study by the Planetary Coral Reef Foundation in 2004 was the abnormally high and persistent sea surface temperature (SST) recorded by NOAA/NESDIS satellites and posted on their web page at www.osdpd.noaa.gov. These satellite images show a record high of 16 DHW (degree heating weeks) around the Phoenix Islands during the months of August 2002 through March 2003 (Fig. 4). "Degree Heating Weeks (DHWs) indicate the accumulation of thermal stress that coral reefs have experienced over the past 12 weeks. One DHW is equivalent to one week of sea surface temperatures one degree Celsius greater than the expected summertime maximum. Two DHWs are equivalent to two weeks at one degree above the expected summertime maximum or one week of two degrees above the expected summertime maximum" (www.osdpd.noaa.gov). NOAA classifies 16 DHW as the existence of high and persistent SSTs that are above the expected summertime maximum which may result in severe bleaching of corals and possible mortality.

The virtual absence of live *Acropora* and *Pocillopora* at site L3 and in the Kanton lagoon in 2004 suggests that these species were intolerant to the increased water temperature and subsequent recruitment has been slow. On the outer reef, live *Acropora* were observed on only one only of six transects. The dominant coral genera noted in 2004 were *Echinopora*, *Favia* and *Montipora* which suggests that these species might be toleratant to increased temperature. *Pocillopora* suffered 90% mortality leaving only a

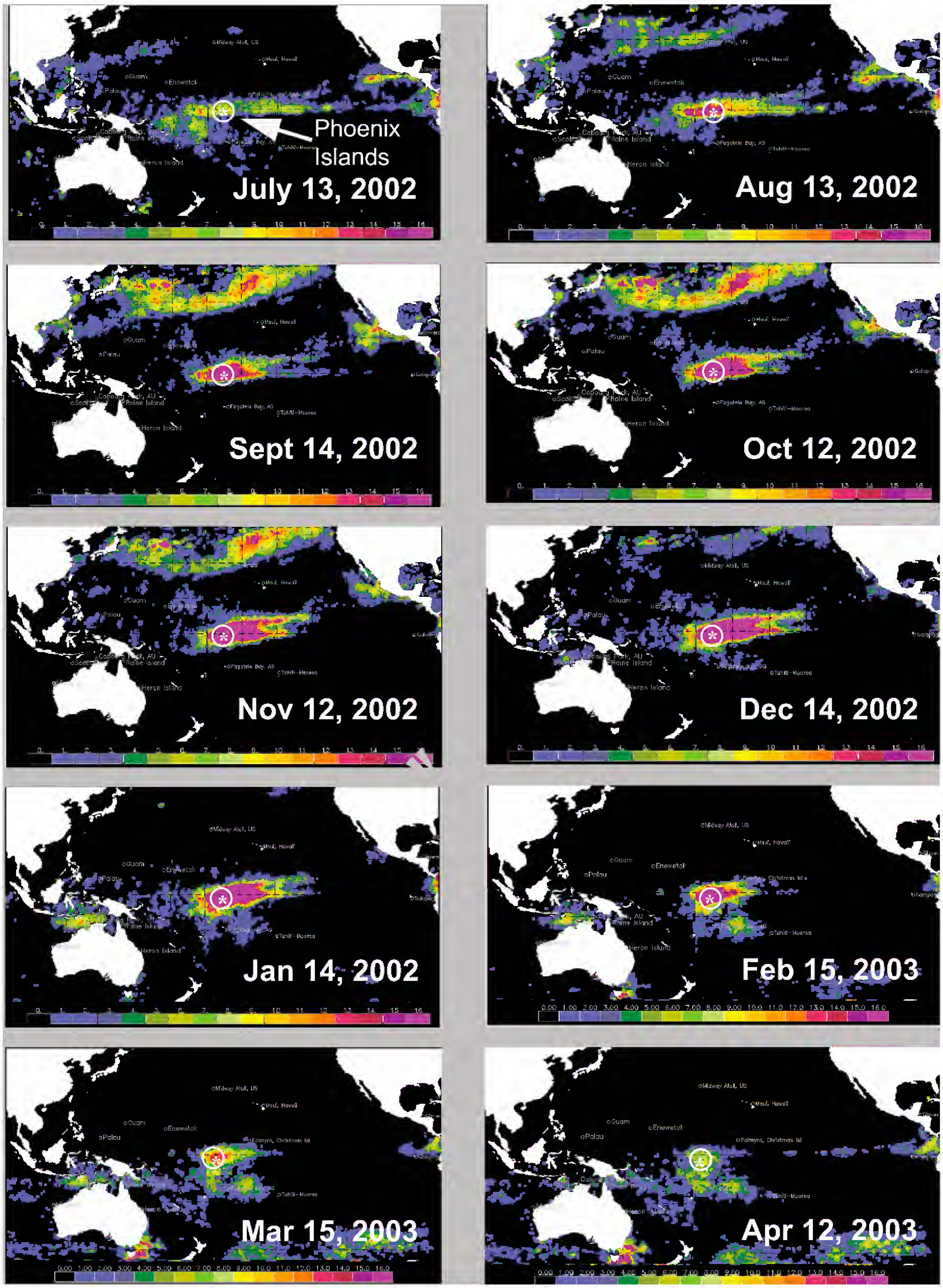

Figure 4: NOAA/NESDIS satellite images of sea surface temperatures from July 2002 through April 2003. The white circle locates the Phoenix Islands (www.osdpd.noaa.gov).

few seed colonies. Similar species shift have been noted in the Indian Ocean which paralleled morphological shifts in some Caribbean coral populations (Loch et al., 2004).

Additionally, R/V Heraclitus researchers did not find tridacnid clams, holothurians or sea stars in the Kanton Atoll lagoon where they had been reported in 2000 by the New England Aquarium. Hence, it would appear that the lagoon community suffered more than just the loss of stony corals, but further study of the invertebrates is required to assess this quantitatively.

Even though the Phoenix Islands are at least 600 km from other islands, at least 85 species from 38 genera of stony corals were identified in 1978 (Jokeil and Maragos, 1978). In 2000, the New England Aquarium expedition recorded 73 coral species at Kanton Atoll alone (Stone et. al, 2001). In 2004, the R/V Heraclitus crew found only 36 species belonging to 24 genera. While some of the decrease between 2000 and 2004 may have been due to under-sampling, thermal hot-spot stress during 2002/2003 may have contributed significantly to the 50% decrease in reef coral biodiversity. Further, Stone et al. (2001) recorded that they collected samples of three possible new species which may have disappeared in the 2002-2003 thermal event. Thus, on a global scale, severe thermal stress may generate selective morphological bottlenecks as well as select more heat-tolerant clades of zooxanthellae (Rowan et al., 1997; Kinzie et al., 2001).

In 2004, coralline algae overgrowing dead corals on the leeward side of Kanton Island were common. In the Maldivian Islands after the 1998 bleaching event, such overgrowth was interpreted as an indication of reef regeneration because coralline algae are suitable substrate for larval recruitment (Loch et al., 2004). It is also likely that the large population of herbivorous fish helped to limit the growth of macroalgae which in turn encouraged the growth of the coralline algae. Coralline algae has been observed by the crew of the R/V Heraclitu*s* at many other reefs in the South Pacific including Papua New Guinea (Kitava), French Polynesia (Bora Bora), Cook Islands (Aitutaki), Tokelau (Atafu) and Tuvalu (Nukufetau, Funafuti). But the team had never before encountered such a high level of coverage on the outer reefs of Kanton, Manra and Enderbury Islands. Curiously, inside the Kanton Atoll lagoon, the dead *Acropora* were colonized by algal mat communities, which trap fine sediment. Unlike the coralline algae, this substrate may slow, or even inhibit, coral recruitment. Only time and careful studies will reveal if this coral community in the lagoon will regenerate or travel down the ecological path to an algal-dominated community (Pandolfi et al., 2005).

Despite the loss of stony corals, the fish populations at Kanton Atoll seemed in good health and the community did not show signs of pressure from over-fishing. Apex predators were present, including sharks and representatives of most reef-fish families. However, there were fewer numbers of sharks recorded in 2004 at Kanton than elsewhere in the Phoenix Group (with particularly dense shark populations at McKean, Nikumroro and Manra Islands) and counts of *Carcharhinus amblyrhynchos* (grey reef shark) were low compared to the Stone et al. surveys (2001). However, *Carcharhinus melanopterus* (blacktip reef shark) was seen at two of the transect sites, T2 and T4, whereas none were observed by Stone et al. (2001). The change in numbers may be attributed to increased long-line shark fishing (Stone et al., 2002) or simply sampling error. Clearly, further studies will be needed to assess the impact of the collapse of the coral reef community on the diversity of fish communities at Kanton Atoll.

Isotopic analysis of coral skeleton cores has demonstrated that the Phoenix Islands have been exposed periodically to warm water pooling driven by the El Nino/La Nina phenomenon (Fairbanks et al., 1997), but these events were not severe enough to cause mortality on the scale that we have observed. In the recent past, reports of mass coral bleaching have been exceedingly rare but increasing in frequency in the Central Pacific.

During the time the R/V Heraclitus was surveying corals in the Phoenix Islands in Nov/Dec 2004, the Pacific Regional Oceanic and Coastal Fisheries (PROCFish) project observed bleaching to the west and south (Friedman, 2004). Between October 4 and November 4, 2004, they noted early stages of a coral bleaching event in Tuvalu and in parts of the Nukufetau Atoll where 10-30% of live corals in the lagoon and passes were affected. Two weeks later, November 12-21, 2004, a recent extensive and significant bleaching incident was observed at Abaiang Atoll, Kiribati where 40-80% coral mortality was noted in shallow water areas with lesser effects to depths of 35m. Coral was also seen bleached in the main atoll of Tarawa and in the southern Gilbertese Group. These bleaching events correlate with the distribution of SST anomalies reported by NOAA (www.osdpd.noaa.gov/PSB/EPS/SST/dhw_retro_2004.html). Thus it would appear that in 2004 another thermal stress-driven bleaching event developed in the Central Pacific that resulted in significant coral mortality.

CONCLUSION

In 2000, the coral reefs of the Phoenix Island group were described as a "biological treasure of national, regional and global significance, and provide a rare opportunity in the South Pacific for conservation and biodiversity research" (Stone et al., 2001). Four short years later, and after the impact of a sustained period of abnormally high sea-surface water temperature in the Phoenix Islands, the coral populations of these once pristine reefs had collapsed. Their remote geography did not provide a refuge from global-scale anthropogenic impacts.

The loss of the pristine reefs of the Phoenix Islands underscores the critical necessity for planetary conservation of coral reefs. Like the 1998 mass bleaching events, in which an estimated 80% or more of the reefs were lost in the Indian Ocean (Wilkinson, 2000), this is yet another example indicating that an abnormal rise in sea-surface temperature can kill reef systems. The NOAA Coral Reef Bleaching Hot Spot project detected the SST warming event while it was in progress, but two years passed before any in-situ information confirming the severity of the event was gathered. In the future, perhaps a rapid response team could be dispatched to such sites.

Had a remote sensing platform capable of detecting shifts in bio-optical reef reflectance been in orbit, the Hot Spot Analysis might have been able to direct its efforts to track ecological events as they unfolded (Dustan et al., 2000, Dustan Et. al., 2001). As the frequency of catastrophic bleaching events appears to be increasing and with the predictions of accelerated global warming (Kerr, 2005), it is becoming more urgent to develop global-scale coral-reef monitoring programs.

For Kanton Atoll and associated islands in the Kiribati Republic, the task has shifted from continuing the basic research of cataloguing fauna and flora, identifying new species, and providing an inventory of the biodiversity for this region, to one of directing resources to follow the future ecological path of its coral reefs. Ironically, this rare catastrophic event has provided an opportunity to demonstrate the widening reach of global warming, to reinforce the view of coral reefs as the indicators of oceanic health, and to provide a test bed to understand better key aspects about the resiliency and sustainability of remote coral-reef ecosystems.

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